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Research paper

Observed trends in temperature and rainfall in Bangladesh using pre-whitening approach

Md. Reaz Akter Mullick[a,*], Ridwan Mohammed Nur[b], Md. Jahangir Alam[c], K.M. Ashraful Islam[d]

[a] Department of Civil Engineering, Chittagong University of Engineering and Technology, Chittagong 4349, Bangladesh
[b] Department of Disaster and Environmental Engineering, Chittagong University of Engineering and Technology, Chittagong 4349, Bangladesh
[c] Department of Sociology, University of Dhaka, Dhaka, Bangladesh
[d] Department of Urban and Regional Planning, Chittagong University of Engineering and Technology, Chittagong 4349, Bangladesh

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ABSTRACT

Understanding the trend of temperature and rainfall is of prime importance for climate change related research. This research aims to identify the trends of temperature and rainfall for the last 50 years (1966–2015) for Bangladesh. To detect the trends, the non-parametric Mann–Kendall test in combination with a trend-free pre-whitening approach for correcting the time series to eliminate the influence of serial correlation has been used whereas the Sen's slope method is used for identification of the trend value. Maximum, minimum, and mean monthly temperatures have been analyzed to identify the monthly, seasonal and annual trend. Four seasons are distinct in Bangladesh, namely, pre-monsoon, monsoon, post-monsoon and winter. In case of rainfall, mean monthly rainfall, 1-day maximum rainfall and consecutive 3-day maximum rainfall are analyzed in a similar fashion. For maximum, minimum and mean monthly temperature, the majority of the stations show an increasing trend for all three indices. Monsoon season observes highest increasing trend of 0.015 °C/yr for mean monthly temperature whereas the winter season shows the negative trend of −0.002 °C/yr. On an annual basis, the trend is increasing with a value of 0.008 °C/yr or 0.4 °C in 50 years having significance level, $p < .05$. On the other hand, mean rainfall shows an increasing trend for the three seasons except for winter, however, significance level in this case is $p > .10$. The trend of mean rainfall for annual basis shows an increasing trend of 5.675 mm/yr. The trend in one day and consecutive three-day maximum rainfall depicts that the trend is increasing in few places whereas in other places the trend is decreasing with no significant change. The research concludes that the climate of Bangladesh is getting cooler and drier for winter, on the other hand, warmer and wetter for the rest of the year.

1. Introduction

Climate that refers to the “average weather” of a place or region includes patterns of temperature, precipitation (rain or snow), humidity, wind and seasons. Climate patterns largely shape the natural ecosystems, human economies and cultures in society. However, the rising levels of carbon dioxide and other heat-trapping gases in the atmosphere have resulted change in climate pattern including rising sea levels; melting of snow and ice; events with changing frequency and extremity of heat and cold wave, fires and drought; storms, rainfall and floods (IPCC, 2007). In the last few decades, the concentration of CO_2 and other greenhouse gases in the atmosphere has increased significantly, largely due to the blazing of fossil fuels and biomass, speedy industrialization, and altering land-use patterns (Khattak et al., 2011).

Inter-Governmental Panel of Climate Change (IPCC, 2007) stated a 0.6 °C (0.4 to 0.8 °C) increase of global temperature during the period of 1901 to 2001indicating warming of the earth in the last few decades. However, IPCC, 2013 mentioned that the global surface temperature towards the end of the 21st century is likely to exceed 1.5 °C relative to 1850 to 1900 for all RCP model scenarios except RCP2.6 (IPCC, 2013). The consequences of this changes pose significant risks to human health, agriculture, freshwater supplies, and supply of other natural resources that are vital to our economy, environment, and quality of life (Mall et al., 2017; Barnes et al., 2013; Yang et al., 2015).

In terms of probable severity and catastrophic impact of climate change, tropical Asia and its coastal belts are in the forefront as

* Corresponding author.
E-mail address: reazmullick@cuet.ac.bd (Md. R.A. Mullick).

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mentioned by several researchers in their studies (e.g. Ali, 1999; Houghton et al., 1990; Huq et al., 1995; Nicholls et al., 1995). According to the Fifth Assessment Report (AR5) of IPCC (2013), seasonal mean rainfall in South Asia shows inter-decadal variability, noticeably a declining trend with more frequent deficit monsoons under regional inhomogeneity. However, other studies reveal that the rate of heavy precipitation measures in South Asia is increasing (Rajeevan et al., 2008; Krishnamurthy et al., 2009; Sen, 2009), while light rain events are decreasing (Goswami et al., 2006). Along this line, an increase in rainfall events has been observed in Bangladesh, and Sri Lanka with a weak decrease over Pakistan as stated by Turner and Annamalai, 2012. However, The inconsistency of decadal variability calls for caution in making definitive conclusions on decadal pattern (Gangan et al., 2017).

Since the changes in climate likely affect the hydrological parameters, studies analyzing the changing pattern of those parameters carry significant scientific value. A number of studies looked into the changing pattern of temperature and rainfall for different spatial and temporal scales in Bangladesh. Jones, 1995 analyzed the monthly mean maximum and minimum temperatures from 1949 to 1989 concluding no significant change over that period. Islam, 2009 analyzed changes in temperature for the last 60 years showing an increase of winter temperature. Climate Change Cell (2009) analyzed the rainfall trend at eight stations along with the temperature and sunshine duration at all BMD stations of Bangladesh. They found seasonal rainfalls have; in general, an increasing trend except during winter and warming has been more rapid in the recent decades. Islam and Neelim (2010) analyzed the maximum and minimum temperatures of four months (December–January and April–May) and two seasons only and the study, in general, found an increasing trend during both summer and winter temperatures. Literature is furthermore available on the variability of rainfall and temperature of India where analysis of temperatures and rainfalls of the Ganges Delta including Bangladesh is found with an increasing trend (Mondal and Wasimi, 2004). However, an in-depth analysis showing the monthly trend of temperature and rainfall for each station is not yet available in the literature. We analyzed the monthly, seasonal and annual trend of temperature and rainfall for all 35 stations in Bangladesh, which might have a direct impact on agriculture because there are varieties of crops in different seasons in Bangladesh. The monthly temperature trend is also necessary for understanding climate extremes (Fischer et al., 2010). The results will give important details to managing climate change adaptation and disaster management (e.g. flood, drought preparedness and crop management).

The majority of the previous studies looked into the second half of the twentieth century where the recent years have been not included (e.g., Qureshi and Hobbie, 1994; Huq et al., 1996; Karim et al., 1999). Moreover, in these studies parametric linear regression technique test for the analysis of trends in temperature and precipitation variables are widely used (Huth and Pokorna, 2004). Correct use of parametric methods, however, requires several assumptions to be fulfilled, including the type of distribution (most frequently normal), serial independence (i.e. zero autocorrelation), and stationarity, which is often not satisfied by climatic data or are difficult to verify as stated by Huth and Pokorna, 2004.

Alternatively, uses of non-parametric (distribution-free) methods relax the assumptions due to its resistance to tolerate outliers. Nonparametric tests for detecting a trend in hydro-meteorological time series are therefore more efficient and used by several researchers (e.g. Yue et al., 2002; Aziz and Burn, 2006; Gemmer et al., 2004; Khattak et al., 2011; Hu et al., 2012). In detecting and interpreting trends in hydrologic data, serial dependency is a notable problem as stated by several researchers. The presence of serial dependency or correlation in the dataset generates misleading signal on trend. Removal of serial correlation of the data series effectively decreases the probability of rejecting the null hypothesis of no-trend (Von Storch, 1995). Some recent studies e.g. Khattak et al., 2011; Hu et al., 2012 analyzed the trend in hydro-meteorological time series after removal of the serial correlation of the dataset.

Shahid, 2010 used the non-parametric Mann-Kendall test (Mann, 1945; Kendall, 1975a, b) to detect the trend and Sen's slope method (Sen, 1968) to determine the magnitude of change in the climate time series for Bangladesh. However, his analysis did not account for the serial correlation of the climate data series. In comparison to Shahid, 2010, our study might be of great impact due to recalculating the facts using pre-whitening of the data set. In Mann-Kendall test, if data is used without removing the serial correlation will either overestimate or underestimate the level of significance (Yue et al., 2002). Kumar et al., 2013a, 2013b studied the global continental area from 60°S to 60°N for the period of 1930–2004 to ensure higher reliability in the observation using CMIP5 historical simulation. He also used the Mann–Kendall (MK) test under two considerations: short-term persistence (STP) (same as Trend Free Pre-Whitening) and long-term persistence (LTP) using Hurst coefficient (H) where the level of significance can be measured by Random Walk test based on LTP. The present study applies the non-parametric Mann-Kendall test for the trend analysis with the Trend Free Pre-whitening (TFPW) approach (Yue et al., 2002) for STP in order to correct time series for serial correlation; however, the Random Walk test is not considered. Finally, Sen's slope method is used to determine the magnitude of change in the climate time series. The study also complements previous work by including recent year's data and all stations' data of the country in the analysis. Multi-decadal variation in the trend has also been considered to identify short spurt or a more constant and gradual change. Therefore, to the best of the authors' knowledge, this paper is the first that carried out the most comprehensive analysis of trends in temperature extremes such as maximum and minimum for Bangladesh, although there are works on temperature and rainfall done previously with little to no consideration on serial correlation. Apart from mean precipitation, the present study also analyzes trends in one day and consecutive three-day maximum rainfall.

2. Description of the study region

Bangladesh extends from 20°34′N to 26°38′N latitude and 88°01′E to 92°41′E longitude. Except for the hilly southeast, most of the country is a low-lying plain situated on deltas of large rivers flowing from the Himalayas. The country is surrounded by the Meghalaya Plateau in the north, the lofty Himalayas lying farther to the north, the Assam Hills in the east and the Bay of Bengal in the south.

Located in the tropical monsoon region, the climate of Bangladesh is characterized by moderately warm temperature, high humidity, with marked seasonal variations in rainfall (Rashid, 1991 as cited by Shahid, 2010). Four distinct seasons are recognized in the country namely, pre-monsoon hot summer for March, April and May, rainy monsoon for the months from June to September, post-monsoon (autumn) from October and November and cool dry winter season from December to February (Rashid, 1991; Shahid, 2010; Murshed and Khan, 2009; Ahasan et al., 2010). January is the coldest month with an average temperature of 18.1 °C and May is the hottest month with average temperature 28.7 °C that the country faces. In the summer the mean temperature gradient is leaning towards northeast (cooler) from the southwest (warmer), in contrary, the winter mean temperature gradient is oriented towards the north (cooler) from the south (warmer). IPCC, 2007 has reported that from 1985 to 1998 there is significant increase in temperature trend of near about 1 °C in May and 0.5 °C in November in Bangladesh.

Rainfall varies from 1400 mm in the west to > 4400 mm in the east, with a west-east gradient of almost 7 mm km^{-1} (Shahid, 2010). Higher rainfall in the northeast is caused by the orographic effect of the Meghalaya. > 75% of the rainfall in Bangladesh occurs during the monsoon season, caused by weak tropical depressions that are brought from the Bay of Bengal into Bangladesh by the wet monsoon winds. Several climate models projected that the temperature would rise 2.4 °C and the rainfall by 9.7% by the end of the present century (Agrawala et al.,

Table 1
Investigated hydro-meteorological indices for trend analysis.

Acronym	Explanation	Unit
MMX	Monthly Maximum Temperature	°C
MMN	Monthly Minimum Temperature	°C
MEAN	Monthly Mean Temperature	°C
MMR	Mean Monthly Rainfall	mm
1-DX	1-d Maximum Rainfall	mm
3-DX	3-d Maximum Rainfall	mm

2003) and the impacts of intense precipitation and extreme weather events are already felt in Bangladesh. Floods recorded in 1988, 1998, 2004 and 2007, and cyclones and tidal surges recorded in 1991, 1998, 2000, 2004 and 2007 are the cases of extreme regarding both frequency and severity (Mallick, 2008).

3. Data and methodology

Six indices, three for temperature and three for rainfall as mentioned in Table 1 were selected for the investigation to describe the different aspects of hydro-meteorological conditions and its trend in Bangladesh. We selected those indices to describe the wide variety of rainfall and temperature characteristics in both the average regime and the extreme behavior processes (Hu et al., 2012). The observed daily temperature and rainfall data of 35 stations all over Bangladesh as shown in Fig. 1 during the period of 1966–2015 (50 years) was collected from the Climate Division of Bangladesh Meteorological Department (BMD). Data was then rearranged into four seasons.

All chosen indices were calculated on a monthly basis except 1-DX,

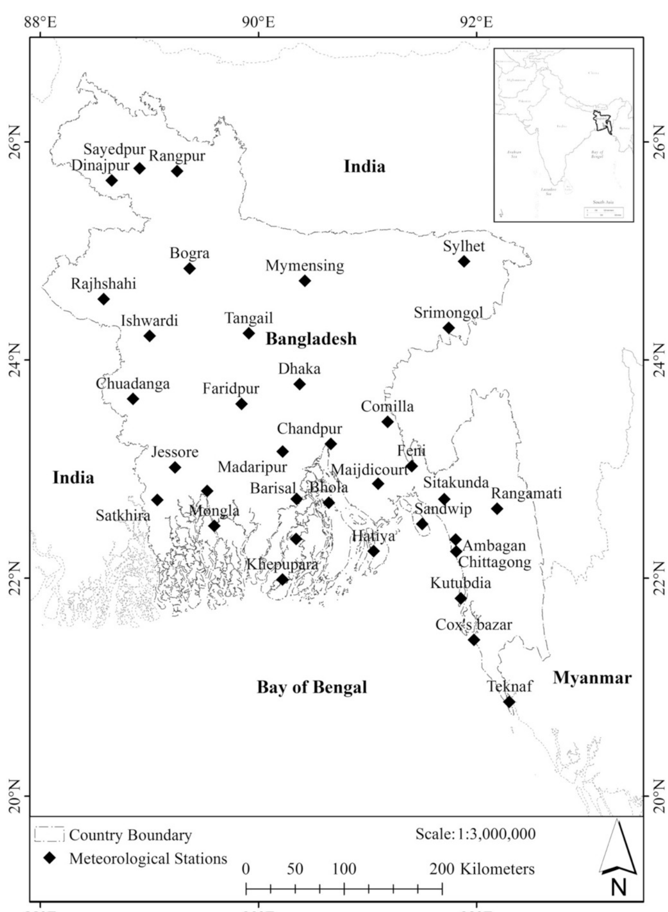

Fig. 1. Location map of 35 Meteorological stations in Bangladesh.

3-DX. For temperature, the indices depicted changes in mean as well as in cold and warm extremes. For precipitation, the amount, intensity and extremes were analyzed as well as the 1-day maximum and consecutive 3-days maximum rainfall as observed during the year is also analyzed. Apart from this, annual trend was also calculated.

As mentioned earlier, the study used non-parametric Mann–Kendall test in conjunction with the method of pre-whitening for removal of serial correlation if such relation exists at 10% significant level. To remove the effect of serial correlation, there are several techniques exist such as Durbin-Watson test, Rank Von Neumann test, Lagrange multiplier test, A Correlogram, The Moran's I statistic etc. However, the techniques suggested by Yue et al., 2002 and used by Aziz and Burn, 2006; Novotny and Stefan, 2007; Burn, 2008; Zhang and Lu, 2009; Kumar et al., 2009 and Khattak et al., 2011 were adopted in the present study.

The Mann-Kendall test is a ranked based approach that compares each value of the time series with the remaining values in a sequential order (Hirsch et al., 1982). The test statistic S is given by:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{Sgn}(x_j - x_k)$$

where

$$\mathrm{Sgn}(x_j - x_k) = \begin{bmatrix} 1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{bmatrix}$$

x_j and x_k are the sequential data values, and n is the length of the dataset. S bearing a positive value indicates an upward trend and opposite for downward trend.

The test follows a normal distribution when the samples $n > 10$ (Helsel and Hirsch, 1992), with the expectation (E) and variance (Var) as follows:

$$E[S] = 0$$

$$\mathrm{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right]$$

Where t_p is the number of data points in the p^{th} tied group and q is the number of tied groups in the dataset. The standardized test statistic (Z) is calculated as:

$$Z = \begin{bmatrix} \dfrac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0 \\ \dfrac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0 \\ 0 & \text{if } S = 0 \end{bmatrix}$$

here, the value of Z is the Mann-Kendall test statistic that follows a standard normal distribution with mean being 0 and variance being 1. Confidence intervals of 90, 95 and 99% ($p < .10$, $p < .05$ and $p < .01$, respectively) were taken to classify the significance of positive and negative temperature and precipitation trends.

The slope of the linear trend has been estimated using the Theil–Sen estimator, also known as Sen's slope estimator (Sen, 1968). The method is widely practiced in the analysis of climatic data (e.g. Kunkel et al., 1999; Zhang et al., 2001; Mashagbah and Farajat, 2013) and outperforms the least-squares regression in computing the magnitude of linear trends when the sample size is large (Zhang et al., 2004). In the case of the availability of more data, more likely the Mann-Kendall test will determine the trend. The sample size has to be at least 100 (Zhang et al., 2004), which is satisfied for this study. The method is efficient and is insensitive to outliers. The slope estimates of N pairs of data are first computed by.

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{For } i = 1....N$$

Table 2
Percentage of stations having decreasing trend (−), increasing trend (+) and no trend (0) in temperature for different seasons over Bangladesh for the period of 1966–2015.

Indices	Trend	Pre Monsoon			Monsoon				Post Monsoon		Winter			Annual
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	
MMX	+	51.4	48.6	65.7	91.4	100.0	97.1	97.1	91.4	68.6	80.0	60.0	48.6	75
	0	5.7	11.4	14.3	2.9	0.0	0.0	2.9	2.9	22.9	11.4	8.6	11.4	8
	−	42.9	40.0	20.0	5.7	0.0	2.9	0.0	5.7	8.6	8.6	31.4	40.0	17
MMN	+	68.6	77.1	77.1	74.3	97.1	94.3	97.1	31.4	40.0	45.7	28.6	65.7	66
	0	8.6	11.4	14.3	17.1	2.9	5.7	2.9	17.1	8.6	5.7	11.4	2.9	9
	−	22.9	11.4	8.6	8.6	0.0	0.0	0.0	51.4	51.4	48.6	60.0	31.4	25
MEAN	+	60.0	54.3	57.1	91.4	91.4	88.6	91.4	54.3	40.0	31.4	14.3	51.4	60
	0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	2.9	0.0	2.9	0.0	0.0	1
	−	40.0	42.9	42.9	8.6	8.6	11.4	8.6	42.9	60.0	65.7	85.7	48.6	39

where x_j and x_k are data values at times j and k (j > k), respectively. The median of these N values of Qi is the Sen's estimator of the slope.

4. Result

4.1. Temperature

Data did not show significant serial correlation except for post monsoon seasonal temperature. In case of monthly temperature, only December month showed the existence of serial correlation. Serial correlation of these time series was removed followed by trend analysis. Table 2 presents the results in percentage of stations with significant negative (decreasing), positive (increasing) and no trend in month, season and annual basis for the three indices as mentioned in Table 1. The country observed an overall increase in temperature for all indices analyzed on annual basis. Sixty percent of the total stations showed an increasing trend for mean temperature and 75% station showed the increasing trend for the maximum temperature.

In pre-monsoon season, particularly in the month of May 66% of the stations show an increasing trend for the maximum temperature whereas > 75% of stations show an increasing trend for the minimum temperature. Around 50% of the stations have increasing trend for mean temperature. This implies that pre-monsoon season is becoming warmer. The changing trend in monsoon season is again noteworthy. For all the three indices, around 90% of stations had an increasing trend in monsoon meaning that almost the entire country faces a hotter summer. In the post-monsoon, maximum temperature (MMX) has an increasing trend for the majority of the stations, however; minimum temperature shows a decreasing trend for > 50% of the stations. Results imply that diurnal temperature difference in post monsoon season is increasing. For the mean temperature in the winter season, majority of the stations showed a decreasing trend and the trend is more pronounced in the month of December and January. The gradual increase in temperature might have an adverse effect on irrigation period and scheduling, evapotranspiration, effective precipitation and soil moisture availability. Daily irrigation rate and groundwater depletion will also increase. Eventually, it will increase the production cost in agriculture sector and hamper the poverty elevation target of the government.

Table 3 represents the result of the change of temperature for three different indices in degree centigrade per year as obtained from Sen's slope analysis. The seasonal analysis as shown in Table 3 revealed that decreasing trend in winter temperature was predominant whereas prevalent warming trend exists in the monsoon, which indicates a hotter monsoon and a colder winter. The result shows that the maximum increase happens in July and August by 0.75 °C in 50 years with $p < .01$, whereas the maximum decrease is observed in the month of January with a value of 0.95 °C in 50 years with $p < .05$. Earlier studies (e.g. Agrawala et al., 2003; Shahid, 2010, 2011; Islam and Neelim, 2010) found an increasing trend in temperature both in summer and winter season. However, the present study reveals a decreasing trend in winter and particularly in December and January. A detailed investigation was carried out to ensure the obtained result. A serial correlation was identified in the month of December. Trend analysis without removing the serial correlation shows an increasing trend whereas the trend analysis after removal of serial correlation confirms a decreasing trend both in December and as a whole for the winter season. Analysis of seasonal mean temperature shows a total decrease in temperature by 0.1 °C in 50 years in winter. Nevertheless, 0.75 °C increase in temperature was noted during monsoon. On an annual basis, the country observed an overall increase of temperature by 0.4 °C in the last 50 years with $p < .05$. Results are quite compatible with previous studies e.g. Ahmed et al., 1996 found an increase in temperature by 0.5 °C in 80 years spanning from 1870 to 1991. Monthly maximum and minimum temperature trend for seasonal basis are also showing an increasing trend.

The trend of mean temperature for individual stations was analyzed and presented in Fig. 2 on a seasonal timescale. Results show that 20 stations observed an increasing trend in pre-monsoon season (Fig. 2a). Increasing trend is mostly observed in the coastal belt and from north to south diagonally. This might be due to sea surface temperature rise at the Bay of Bengal as stated by Salahuddin et al., 2006. In the monsoon, 32 stations meaning that almost the entire country showed an increasing trend of temperature. The highest increase occurred in the northern part of the country (Fig. 2b). Out of these 32 stations, 29 stations show the increasing trend at 1% significance level (p-value < .01). Fig. 2c shows the station wise temperature trend for the post-monsoon season where 15 stations show increasing whereas 20 stations have a decreasing trend. Increasing trend is again observed prevalent from north to south diagonally. On the other hand, 23 stations i.e. more than half of the country show a decreasing trend in mean temperature for winter (Fig. 2d).

Yearly mean land surface temperature pattern over Southeast Asia is increasing at a rate of 0.14 °C to 0.20 °C in every decade since the 1960s (IPCC, 2013). Shahid, 2010 estimated 0.097 °C change in mean temperature per decade in overall Bangladesh, which is close enough with the obtained result of 0.084 °C change in mean temperature per decade. Shahid, 2010 also estimated a significant increase in mean temperature all over Bangladesh that complies with the present analyses and results. However, this research finds Sayedpur and Rangpur in the northern part of Bangladesh showing a significant increase in temperature in premonsoon and monsoon which contradicts the comment of Shahid, 2010. Results carry importance for climate action plan formulation at government level and particularly for irrigation plan and scheduling. Eventually results from the study will help the community to reduce climate-induced economic losses.

The analysis of Multi-decadal change in temperature is also carried out and presented in Fig. 3. The Analysis reveals that variation of temperature change is uneven for the winter season. The fluctuation is quite significant and follows an alternate increase and decreasing

Table 3
Change in mean temperature for Monthly, Seasonal and Annual basis and MMX, MNN for Seasonal basis (°C per year) over Bangladesh (*$p < .10$, **$p < .05$, ***$p < .01$) for the period of 1966–2015.

Parameter	Pre Monsoon			Monsoon				Post Monsoon		Winter		
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Mean Monthly change	0.009	−0.001	−0.004	0.014***	0.015***	0.015***	0.010***	0.004	−0.004	−0.003	−0.019**	0.015
Mean Seasonal change	0.001			0.015***				0.0005		−0.002		
MMX Seasonal Change	0.006			0.028***				0.025***		0.006		
MNN Seasonal Change	0.010*			0.014***				0.006**		0.016**		
Mean Annual change	0.008**											

pattern for the decades analyzed. However, there might have an edge effect, which has not been considered. For the other three seasons, temperature shows a decreasing trend from 1966 to 1980 and then a gradual increase up to 2015.

4.2. Rainfall

Results on rainfall analysis are summarized and presented in Table 4 in a similar fashion as it was done for temperature. In case of monthly rainfall, the country as a whole observed no significant trend for all the three indices analyzed. Mean monthly rainfall in monsoon season, around 50% of the stations had positive trend whereas the remaining had a negative trend. In contrast, during the winter season, almost all the stations showed no trend for all three indices analyzed. For December and January, the majority of the stations showed a 'zero' trend. Shahid, 2010 estimated a significant increase in rainfall during pre-monsoon and the current study also found an increase in rainfall in that season but not significant. The changes in rainfall during monsoon and post-monsoon is significant for only a few stations. Nevertheless, our result differs in case of winter where significant decreases of rainfall are observed. This result does not support output of Shahid, 2010 for winter where he said change is slightly significant for a handful of stations. However, Shahid, 2010 has shown an annual increase of rainfall of 5.53 mm per year for all over Bangladesh, which is quite similar to our result of 5.68 mm increase per year. In our study, the lowering trend of rainfall is predominant from November to April (Table 5) and an increasing trend is observed during May to October (Table 5). Results imply that monsoon is going to be wetter, however; winter and partly the post and pre-monsoon season is becoming drier.

From Table 5 it is evident that the highest increasing trend is found in May (pre-monsoon season) and October (Post-monsoon season) and conversely, the highest decreasing trend is observed in April. All the months in winter season showed a decreasing trend and insignificant also. In seasonal scale, pre-monsoon, monsoon and post-monsoon had an increasing trend and the highest change is observed in the monsoon with a value of 3.3 mm/year. The change of rainfall in winter was 0.055 mm decreasing in each year. Climate models show small decreases in precipitation in the winter months of December through February (Agrawala et al., 2003). Singh, 2001 reported that the monsoon rainfall over Bangladesh increased during the period of 1961–1991 with a maximum increase in September followed by July, which is quite similar with the results of this study. The rainfall in pre-monsoon is mainly due to thunderstorms as stated by Sanderson and Ahmed, 1979. The activity of this seasonal thunderstorm is mainly caused due to supply of moist air from the Bay of Bengal. Increased sea surface temperature results stronger and more continuous winds from the Bay of Bengal (Khan et al., 2000; Salahuddin et al., 2006), which subsequently increases the thunderstorm activity, which might be the reason behind the increasing trend of rainfall in pre-monsoon season. The increase of precipitation in summer monsoon is the result of warmer land air than ocean air and deepening of the low-pressure system on land enhances the monsoon.

Analysis from this study also identified an increasing rainfall trend in the southeast part of the country particularly in the pre-monsoon and post-monsoon season. Due to the hilly area at the southeast part of Bangladesh, it's highly prone to landslide. Increasing rainfall trend may result in more landslide events. Such analyses and results will push government to develop landslide mitigation plan. Agriculture in the southeast hilly region needs special considerations as soil moisture content might increase due to increase in rainfall.

Fig. 4 presents the trend of mean rainfall for individual stations. Results show that 23 stations had an increasing trend in pre-monsoon season. The figure also revealed that eastern hill and north-eastern region of the country show the increasing rainfall trend and the central part experiences a decreasing trend. However, in the monsoon season fourteen stations mainly in the coastal zone have an increasing trend. In post monsoon, 25 stations show an increasing trend. The increasing pattern largely happens in the coastal region and the maximum and significant increase occurred in Teknaf, the most southern point of the country. Nineteen stations showed a decreasing trend in mean rainfall for winter, however; the significant decreasing trend is observed at Mongla, Feni, Tangail and Sayedpur. In case of maximum 1-day and 3-day rainfall, the extreme events had occurred in recent years. However, this does not certainly mean that extreme rainfall events have increasing trends. For both the indices, one-third number of stations have positive, one-third no trend and one-third number of stations have negative trend as presented in Table 4. The multi-decadal analysis for the rainfall change shows a negligible trend in the winter season (Fig. 5). Pre-monsoon and monsoon season does not follow uniform pattern rather it shows alternate increasing and decreasing trend for the decades analyzed. However, edge effect might exists which has not been considered in this study.

According to the observation of IPCC, 2013 report, the obtained results are consistent for monsoon rainfall. The report has projected a decrease in winter rainfall and an increase in monsoon rainfall, which is similar to the trend obtained. Changing seasonal rainfall pattern will eventually change in agricultural water demand. Shahid, 2011 stated that the decrease in rainfall in winter will result soil moisture deficiency and finally will demand more water for land preparation particularly for Boro rice production in Bangladesh. Rodrigo, 2002 and Su et al., 2006 mentioned that small changes in the mean of temperature and rainfall could cause relatively large changes in the probability of extreme events that will ultimately result in more extreme weather events and related disasters in future. The occurrence of cholera and diarrheal diseases is directly and positively correlated to rainfall intensity and temperature as stated in several literature e.g. Rowland, 1986; Hashizume et al., 2007.

5. Conclusion

Trend analysis using a pre-whitening technique for the temperature and rainfall data of last 50 years (1966–2015) and of 35 stations of Bangladesh, it is evident that the country is experiencing a significant increasing trend in temperature and rainfall all the year round except winter. Annual mean temperature change over the country is 0.008 °C/yr and rainfall change is 5.68 mm/yr based on the period analyzed.

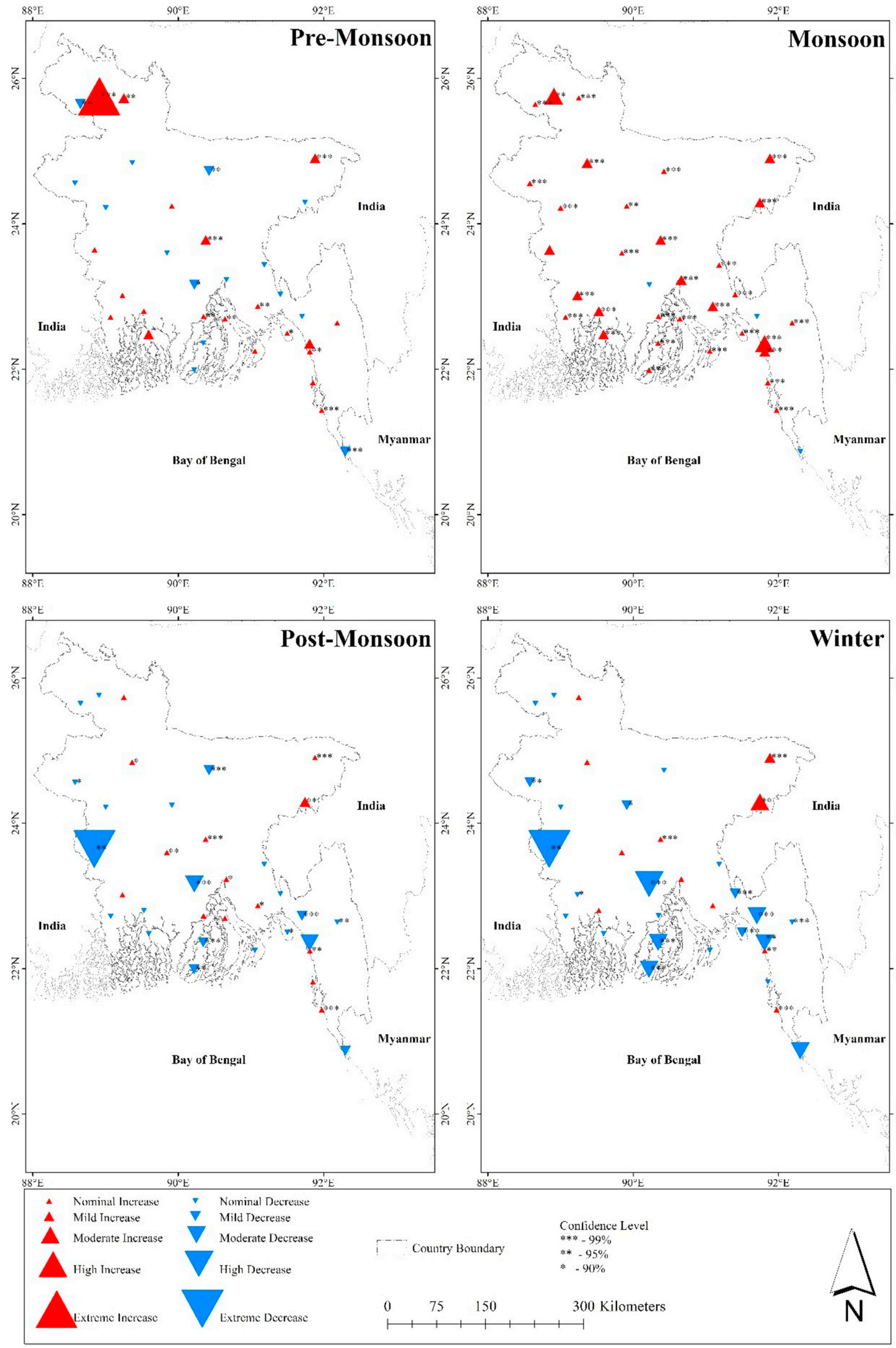

Fig. 2. Seasonal temperature trend for 50 years (1966 - 2015) at different meteorological stations of Bangladesh. In the key- Nominal 0-1°C, Mild 1-2°C, Moderate 2-3°C, High 3-4°C, Extreme > 4°C

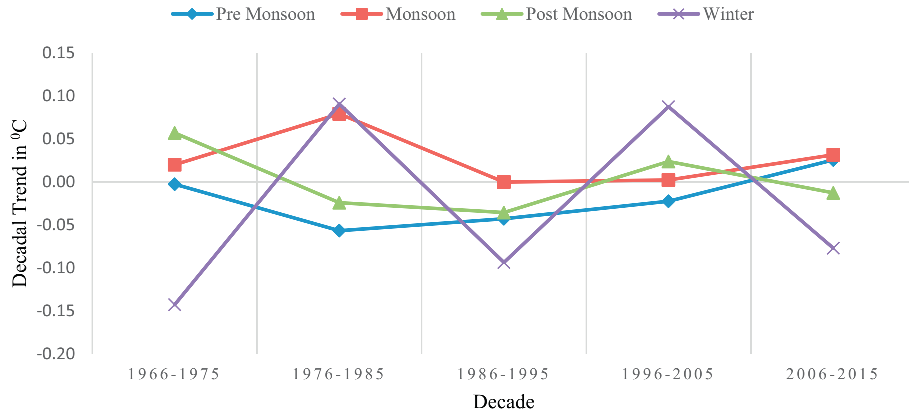

Fig. 3. Multi-decadal changing pattern of seasonal temperature.

Table 4
Percentage of stations having decreasing trend (−), increasing trend (+) and no trend (0) for rainfall indices for different seasons over Bangladesh for the period of 1966–2015.

Indices		Pre Monsoon			Monsoon				Post Monsoon		Winter			Annual
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	
Monthly Rainfall	+	45.7	51.4	65.7	37.1	54.3	28.6	65.7	82.9	0.0	0.0	0.0	17.1	37.4
	0	40.0	5.7	5.7	5.7	2.9	5.7	2.9	5.7	60.0	100.0	94.3	62.9	32.6
	−	14.3	42.9	28.6	57.1	42.9	65.7	31.4	11.4	40.0	0.0	5.7	20.0	30.0
1 day Rainfall	+	45.7	34.3	54.3	37.1	40.0	34.3	62.9	88.6	0.0	0.0	0.0	14.3	34.3
	0	28.6	2.9	11.4	2.9	2.9	5.7	0.0	0.0	65.7	100.0	94.3	54.3	30.7
	−	25.7	62.9	34.3	60.0	57.1	60.0	37.1	11.4	34.3	0.0	5.7	31.4	35.0
3 day Rainfall	+	51.4	42.9	71.4	37.1	45.7	42.9	62.9	85.7	0.0	0.0	0.0	20.0	38.3
	0	37.1	2.9	0.0	0.0	2.9	5.7	0.0	0.0	65.7	100.0	94.3	62.9	31.0
	−	11.4	54.3	28.6	62.9	51.4	51.4	37.1	14.3	34.3	0.0	5.7	17.1	30.7

Both the winter temperature and rainfall have a decreasing trend. Increase in the Bay of Bengal sea surface temperature is evident from Khan et al., 2000 and positive relation is found between sea surface temperature and increase in rainfall in Bangladesh particularly in the monsoon (Salahuddin et al., 2006; Cash et al., 2007). The increase in rainfall in Bangladesh as obtained from the study therefore in line with the previous research and possibly due to the result of increased sea surface temperature of the Bay of Bengal as mentioned in IPCC, 2013.

Such changes in temperature and rainfall might have a number of implications for agriculture (Karim et al., 1999), water resources (Fung et al., 2006) and public health. Irrigation water demand is affected by rainfall. Since evapotranspiration rate is a driver of irrigation water demand, change in temperature therefore, has a passive impact on it (Shahid, 2011). The rise in maximum temperature has an adverse effect on crop phenology (Shahid, 2011). Increased rainfall can help to keep the groundwater levels in balance; however, a decrease in winter rainfall will certainly have an impact on agricultural system and result in increased pressure on irrigation. Bangladesh is already recognized as a disaster-prone area and such changes in temperature and rainfall may result in more extreme weather events and related disasters. Analyses and result from the study will help in designing climate resilience policy formulation for the different sector at the public, private and community level.

Author attribution

Dr. Reaz Akter Mullick, the corresponding author, received the research grant. He gave necessary guidance and his intellectual inputs for conducting this research work.

Ridwan Mohammed Nur, was the research assistant who built a proper methodological framework and collected, analyzed and represented all the data for conducting this research work.

Md Jahangir Alam, reviewed the literatures and also put his intellectual on results and conclusion.

K. M. Ashraful Islam, was the research assistant who prepared necessary maps and illustrations, compiled the data and reviewed and edited the whole manuscript in a presentable format.

Disclosure of potential conflicts of interest

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Table 5
Monthly, seasonal and annual Change in rainfall over Bangladesh for the period of 1966–2015. (**$p < .05$, ***$p < .01$).

Parameter	Pre Monsoon			Monsoon				Post Monsoon		Winter		
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Monthly change	−0.001	−0.305	1.852**	0.546	0.992	0.005	1.370**	1.681**	−0.225	−0.041	−0.007	−0.013
Seasonal change	1.019			3.313				1.205		−0.055		
Annual change	5.675**											

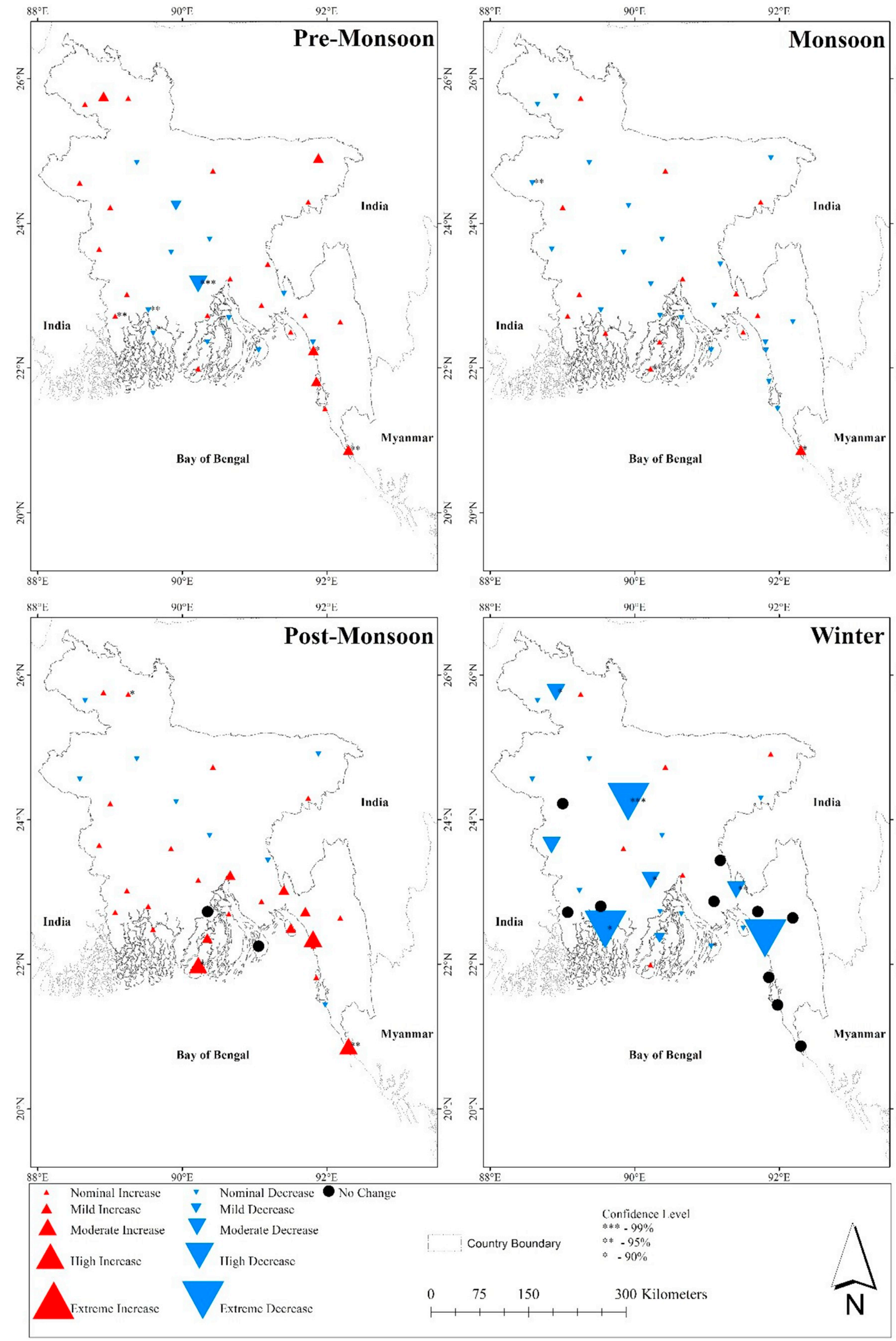

Fig. 4. Seasonal rainfall trend for 50 years (1966 - 2015) in different meteorological stations of Bangladesh In the key- Nominal 0-1%, Mild 1-2%, Moderate 2-3%, High 3-4%, Extreme > 4% rainfall (in percent of total).

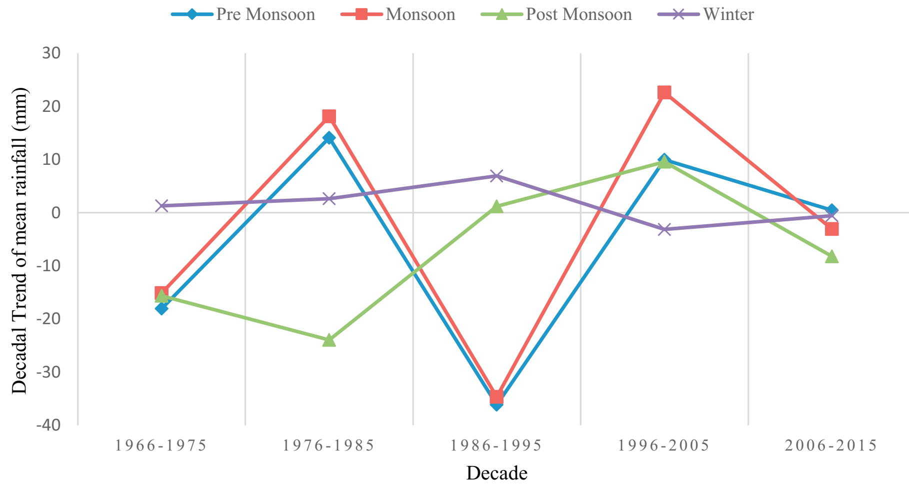

Fig. 5. Change in rainfall in Multi-decadal time scale for the period of 1966-2015.

Conflict of interest

The authors declare that they have no conflict of interest.

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